

Enabling Interplanetary Small Spacecraft Missions

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- Investigate concepts for low-cost Mars science missions
- Goals for all mission concepts studied:
 - The mission should be science driven, with goals traceable to the Decadal Survey, MEPAG goals, HEO SKGs, etc.
 - S/C mass target: less than about 100 kg to 300 kg
 - Mars Transport options*:
 1. Rideshare on a Mars-bound mission, or
 2. Rideshare GTO/GEO and other trajectories
 - Mission cost goal about \$100 M to \$150 M
 - Provide concept examples for both Orbiters (high and low orbits) and Landers

*Not considering dedicated launch due to cost constraints

Rideshare to Mars

Only a few Mars-bound launch opportunities:

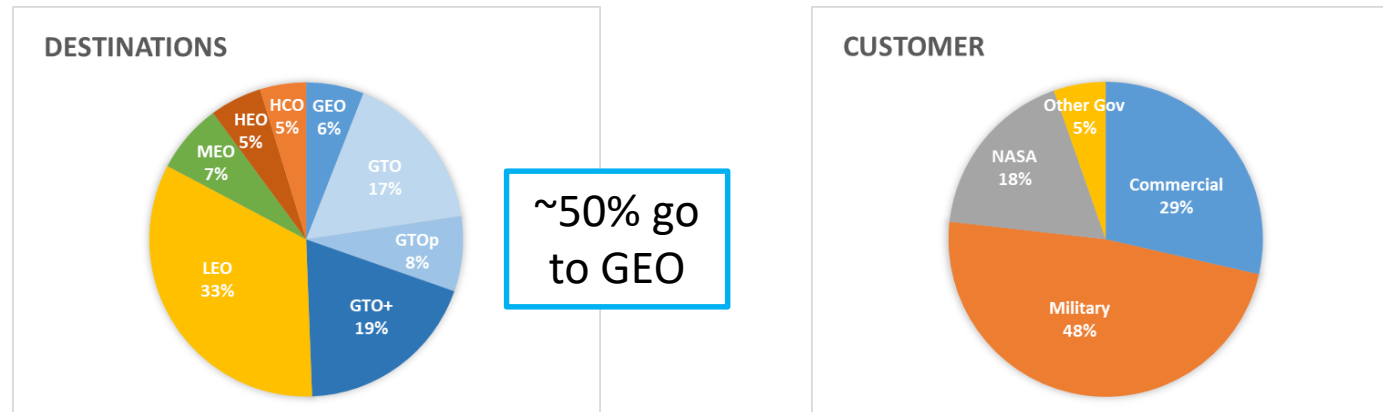
- InSight (2018)
- Future “Planned” Mars or Close-to-Mars missions:
 - Mars2020 (2020)
 - Psyche (2022, flyby in 2023)
 - Potential Mars Sample Return (MSR), Lander and Orbiter ... (TBD)
 - International opportunities, ESA/RSP in 2020, UAE, MMX

or

Make Your Own Way

- Use extra launch capacity of vehicles not going to Mars
- Need own propulsion
- Increasing ΔV requirements:
 - Earth Escape
 - Lunar Flyby
 - Super GTO
 - GTO/GEO
 - LEO
- Planetary phasing can be problematic

- Since 2002: 168 total launches of Atlas V, Delta 4, and Falcon 9



- In the last 5 years (103 launches):
 - ~10 launches per year to GTO/GEO, ~2/yr go beyond
 - 2/3 of those are government launches
 - Many have excess capability

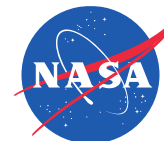
Excess Payload Capacity



- Excess payload capacity is available on government, NASA, and commercial missions.
- Creates an opportunity to send small spacecraft on interplanetary missions on each of these launches.
- Transit to C3=0 with excess LV capacity, chemical, or electric propulsion.

Selected data from: Bob Caffrey "Using Rideshare to Launch CubeSats and ESPA S/C." GSFC, 2017

| NASA Mission | Estimated Launch Date | Orbit | Launch Vehicle | Secondary P/L Capable | Excess Mass (kg) |
|----------------|-----------------------|----------|----------------|--|------------------|
| Landsat-8 | February-2013 | SSO | Atlas V | Yes | 4400 |
| DSCOVR | February-2015 | E-5 L2 | Falcon 9 | Yes | 2500 |
| TDRS-M | October-2017 | GTO | Atlas V - 401 | Yes | 271 |
| TESS | December-2017 | TLI | Falcon 9 | Yes | 3000 |
| Landsat-9 | June-2021 | SSO | Atlas V - 401 | Yes | 4400 |
| SWOT | April-2021 | LEO i=77 | Falcon 9 | No | 5080 |
| Sentinel-6 | December-2021 | LEO i=66 | Atlas V - 401 | No | 7760 |
| Lucy | October-2021 | Helio | TBD | Yes | TBD |
| Pysche | August-2022 | Helio | TBD | Yes | TBD |
| MIDEX | NLT December-2023 | Helio | TBD | Yes | TBD |
| IMAP | NLT December-2024 | Helio | TBD | Yes | TBD |
| New Frontiers | NLT 2025 | Helio | TBD | Yes | TBD |
| Discovery 2018 | NLT 2026 | Helio | TBD | Yes | TBD |
| NEOCam | NLT 2026 | Helio | TBD | Yes | TBD |
| GOES-T | 21-Jun | GTO | Atlas V - 541 | Yes? | TBD |
| GOES-U | 24-Apr | GTO | Atlas V - 541 | Yes | TBD |
| Solar Orbiter | 20-Feb | Helio | Atlas V - 411 | TBD for excess perf (could add an SRM) | TBD |



- Offers **flexibility for frequent Mars access** utilizing many government and commercial launches
- Mission designs could utilize current advances in **Solar Electric Propulsion (SEP)** or chemical technologies
- Lower cost spacecraft can offer **compelling science** that would otherwise not be achieved
 - **Lower cost** compared to dedicated launch, spacecraft form factor, more than one spacecraft can spread the risk
 - Small S/C Bus and COTS components available and under development
- **Highly flexible, repeatable model** allows for future interplanetary exploration using secondary payloads

Opportunity for **low cost, higher risk** missions to answer HEO strategic knowledge gaps (SKG's), MEPAG Goals, and Decadal Survey goals.

Atmospheric
Composition

Weather
Monitoring

Surface
Mineralogy

Lightning
Detection

Magnetometry

Radiation
Science

Gravity Science

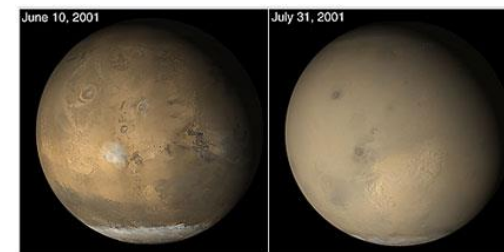
Exogenic influx
(Meteors)

4D weather
monitoring

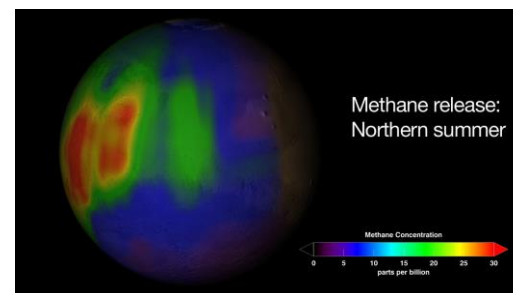
Trace Gas
Localization

Cloud
Properties

Wind
Monitoring



Mars Climate Monitoring

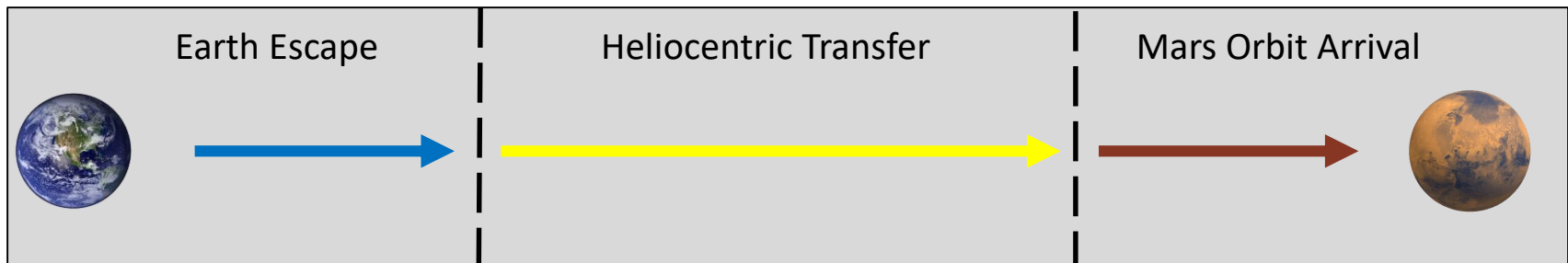


Trace Gas Localization



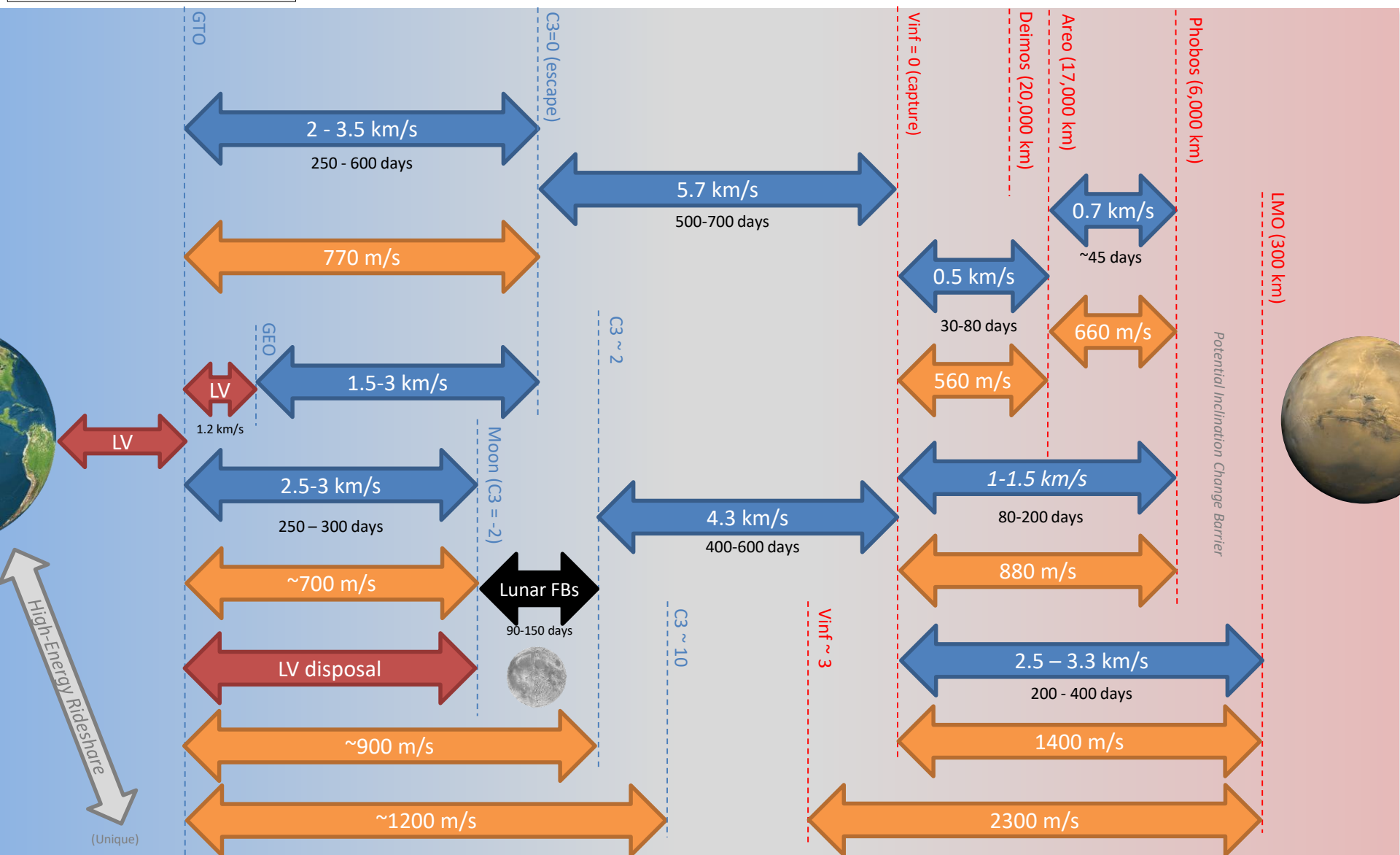
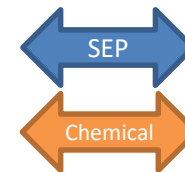
Exogenic Influx

- Tasks for small sat propulsion system:
 1. Escape Earth gravity starting from rideshare orbit (nominally GTO)
 2. Traverse interplanetary space to Mars ($> 5 \text{ km/s } \Delta V$)
 3. Achieve desired Mars orbit (nominally Areostationary)
- Propulsion Options:
 - Chemical Propulsion – Biprop (325 sec), Mono (225 sec), Solid (285 sec)
 - Pros: Heritage, fast, gravitationally efficient
 - Cons: High propellant fraction, not flexible
 - Solar Electric Propulsion (SEP) – 1500-2000 sec, 50-60 mN/kW
 - Pros: Very efficient, flexible to time constraints and orbits, no critical events
 - Cons: Requires lots of power, lower heritage, slower flight times



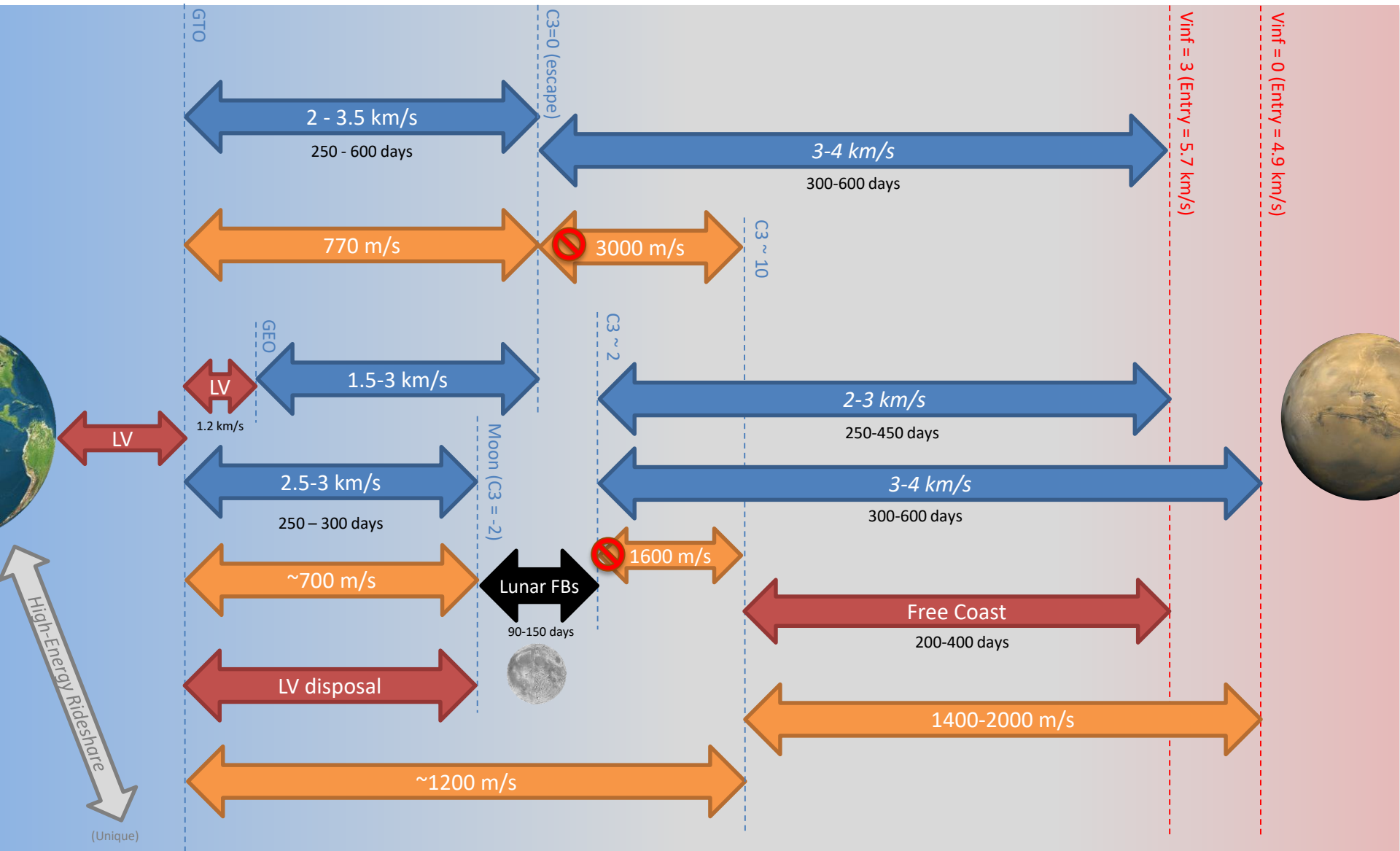
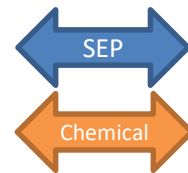
- Notes:
- ΔV 's are approximate
 - ΔV 's don't necessarily add, especially with SEP
 - SEP ΔV 's based on 300 kg and 45 mN
 - Most values require proper Earth-Mars alignment (i.e. Launch/arrival dates)
 - Positive C3 departures require correct asymptote, C3=0 does not

Mars Orbit Via Rideshare



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Mars Entry Via Rideshare



Artist's Concept

Notional Mission – Areostationary Relay

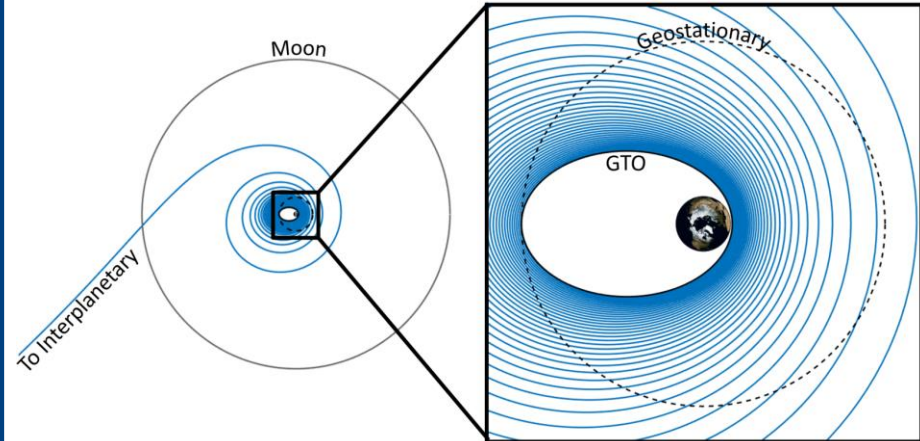


Jet Propulsion Laboratory
California Institute of Technology

Mars Formulation – Small Spacecraft Studies

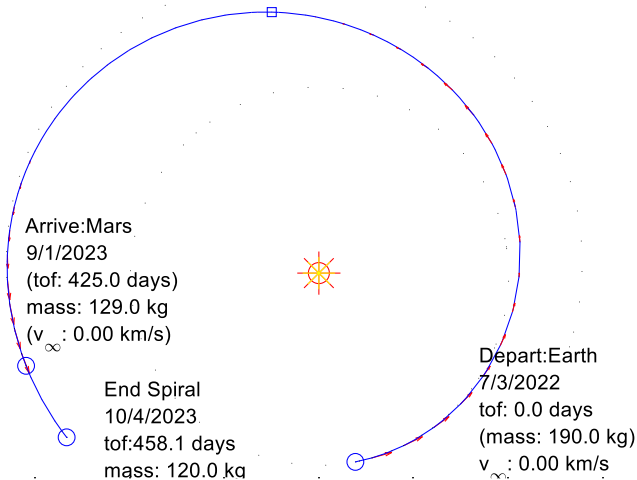
- All SEP from GTO to Areostationary
 - ESPA Ring Rideshare (220 kg)
 - 1 x PPS-1350G thruster (SMART-1)
 - $P_0 = 2.5$ kW at Earth
- 1.85 years total transfer time
- 120 kg dry mass at Mars
- 9 km/s total ΔV and 100 kg of xenon

1. Spiral Out from GTO



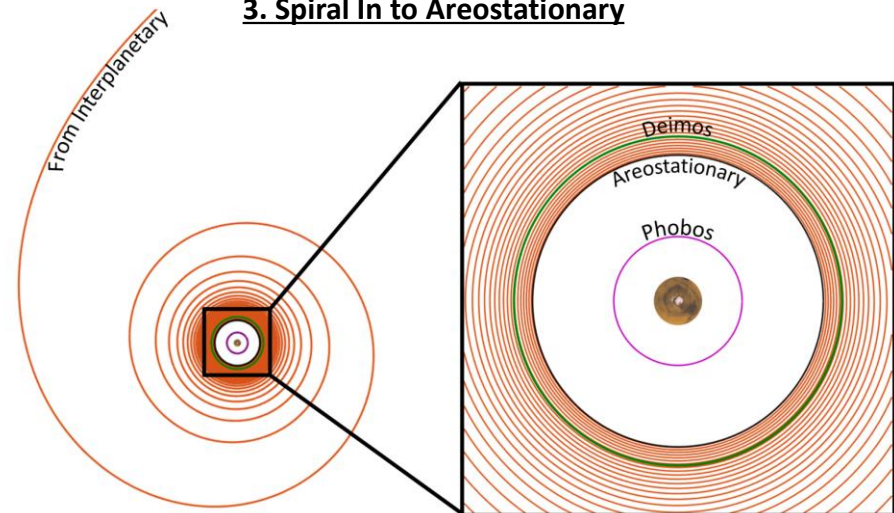
Initial Mass: **220 kg** Xe Used: **30 kg** ΔV : **1.6 km/s** Duration: **7 mos.**

2. Interplanetary Low-Thrust Transfer



Initial Mass: **190 kg** Xe Used: **61 kg** ΔV : **5.7 km/s** Duration: **14 mos.**

3. Spiral In to Areostationary



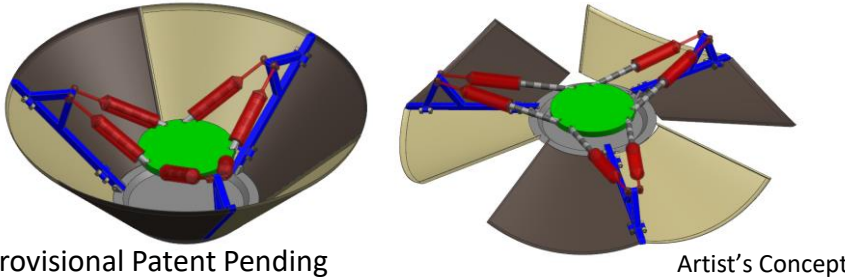
Initial Mass: **129 kg** Xe Used: **9 kg** ΔV : **0.9 km/s** Duration: **1 mo.**

Other Examples of Potential Mars Small S/C Concepts



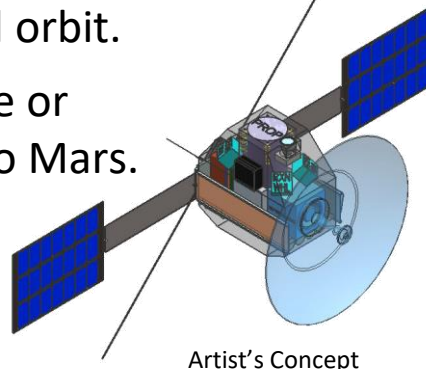
SHIELD*: Small, High Impact Energy Landing Device

- Small (≤ 10 kg entry mass, ≤ 1 m projected diameter)
- Multifunctional structure limits landing deceleration and dissipates associated kinetic energy (no bounce)
- Deliver 2-4 kg of science payload to Martian surface



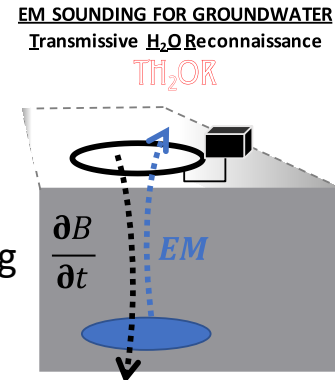
Mars Aerocapture

- Insertion into Mars low orbit by changes in ballistic coefficient (deployable drag skirt) to manage terminal energy state and achieve desired orbit.
- Self-propelled cruise or rideshare payload to Mars.
- 50kg to 100kg dry mass.



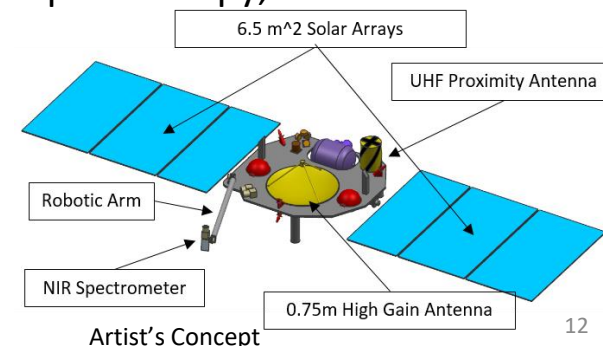
TH₂OR

- Low frequency (Hz-kHz) electromagnetic (EM) detection of groundwater (up to ~ 10 km depth).
- Loop generates $\partial B / \partial t$, causing eddy currents in aquifers, and measurable induced voltage (EM) in surface loop detector.
- < 5 kg and < 10 W feasible.



Phobos Ranger

- Surface lander on Phobos or Deimos.
- Self-propelled cruise or rideshare payload to Mars.
- Phobos/Deimos gravity field investigation, surface mineral spectroscopy, ...

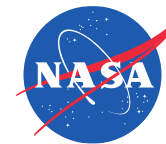


- In the era of the potential future large flagship missions (James Web Telescope, Mars Sample Return, Europa, etc.), which are infrequent and costly, NASA may want to pursue a number of smaller, less expensive missions to maintain the science continuity.
- Scientifically exciting low cost Mars missions using small spacecraft are on the “technology horizon”.
- Although larger in mass than their smaller CubeSat cousins, these small spacecraft build on the technology progress brought by CubeSat community, and advances in low thrust mission design.
- An ongoing study presented here points to the great value that can be gained by utilizing secondary payload opportunities from government and commercial launches with excess launch mass capability.

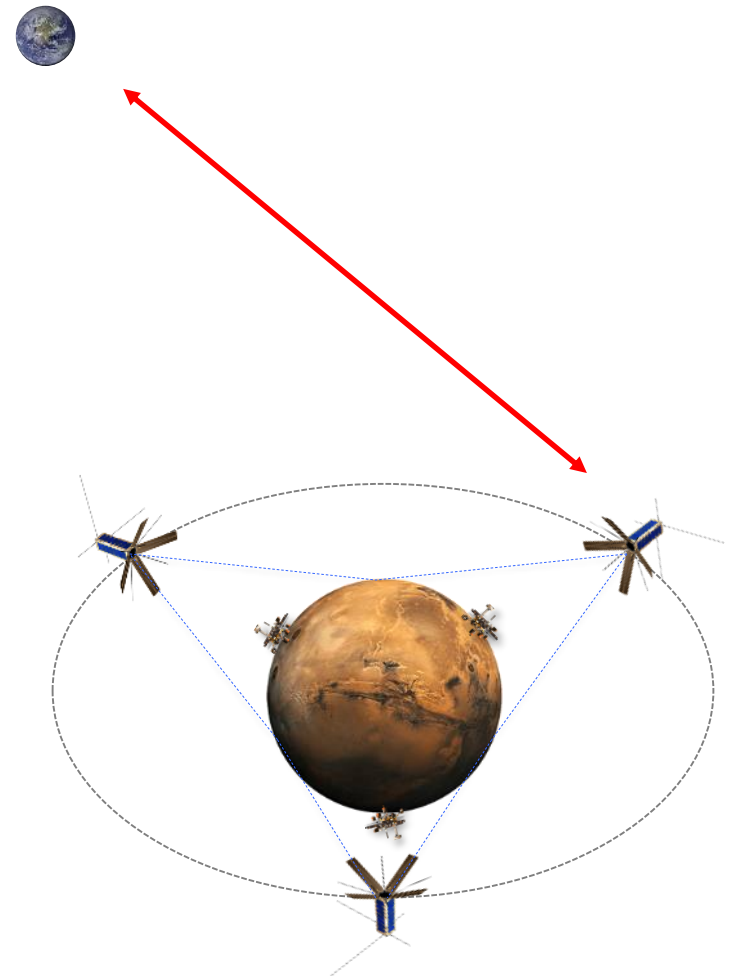


BACKUP

Example Areostationary Constellation

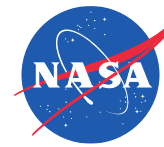


- 3 high altitude (17,000 km) small orbiters
- Function:
 - Constant science coverage of Mars surface and atmospheric phenomena.
 - Suitable for long-term climatology record (dust storm, temperature, pressure, opacity, atmospheric composition, etc)
 - 4D (3D spatial and in time) monitoring over the whole planet (sources of outgassing e.g. methane, water, CO₂)
 - Telecom relay to Earth for Mars surface assets.
 - Precursor for future telecom connectivity for human exploration missions to Mars
- Replenish constellation every 7 years



Artist's Concept

Example Areostationary Small S/C Concept



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Mars Formulation – Small Spacecraft Studies

MASS

- Wet mass NTE: ~220-350kg
- Dry mass NTE: ~120 -190kg

S/C BUS

- Secondary P/L ESPA launch
- Up to 1kW EOL @ 1.65AU
- SEP, 1 to 2 ~1kW Thruster(s)
- Single-string
- Rad-hard avionics

ORBIT

- Spiral up to $C3=0$
- Spiral down from $C3=0$
- Areostationary (17,000km)

SCIENCE

- Long-term weather Monitoring
- Atmospheric monitoring over 4D (sources, sinks, causality)
- Exogenic delivery?

- DTE – Ka/X Band
- Cross link - X-Band
- Proximity - X-Band

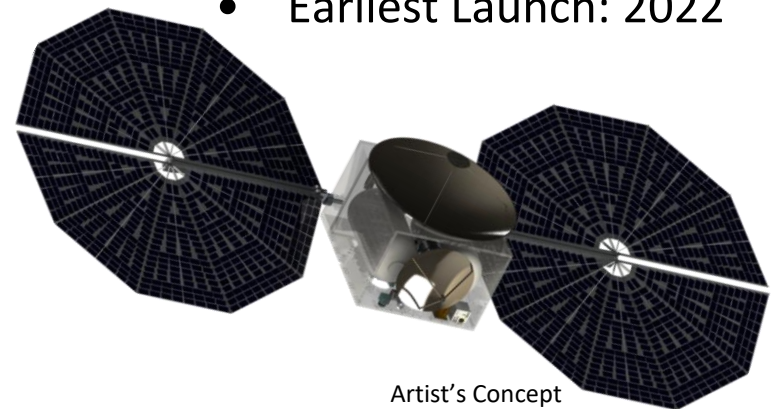
- DTE – ~300kbps @ 1.5AU
- Cross link – XX kbps
- Proximity – XX kbps

- Cost goal < \$150M
- Lifetime > 3 years on orbit
- Earliest Launch: 2022

TELECOM

DATA RATES

PROGRAMATIC



Artist's Concept

EXAMPLE AREOSTATIONARY SMALL SPACECRAFT TELECOM CONOPS

